Analysis of Tower Footing Resistance Effected Back Flashover Across Insulator in a Transmission System

P. Yadee and S. Premrudeepreechacharn

Abstract-- **This study describes analysis of tower footing resistance effected the backflash voltage across insulator in a transmission system. This paper studies the 115 kV transmission lines from Lampang substation to Lamphun substation which is double circuit in the same steel tower with overhead ground wire, 73 kilometers length each. The factor of this study includes magnitude of lightning stroke, front time of lightning stroke, and structure of tower. The frequency dependent model is used as model of transmission between substations. Steel tower uses Bergeron line model. The assumption of studies based on the return stroke current ranged 1-200 kA, front time of lightning stroke between 1.2 μs to 50 μs and insulation strength using 550 kV BIL class insulators. The simulations study the effect of varying tower footing resistance that affect the lightning current. Simulation results are analyzed lightning overvoltage that causes back flashover at insulators. The simulation results are compared with TFlash program. This study helps to know causes of problems of backflash the transmission line system, and also be as a guideline solving the problem for 230 kV and 500 kV transmission line systems.**

***Index Terms*—Tower footing resistance, back flashover, insulator.**

I. INTRODUCTION

In this study, the overvoltage in 115 kV transmission line systems in the northern of Thailand is described. Northern of Thailand has wide range of grounding conditions. However, it is mostly mountain terrains. The transmission lines in northern part of Thailand have many events caused flashover and damage the insulators in transmission line. Faults on the transmission system cause the major interruptions.

The power system network, considered in this study as shown in Fig. 1, is 115 kV line between Lampang 2 (LP2) and Lampun 2 (LN2) circuit 1 and 2. The configuration of tower is double circuit with one overhead ground wire, 73 kilometers length. The tower is steel tower. This line has totally 213 towers. From the records between 1998 and 2003, the flashover insulators often occurred at 115 kV as shown in Fig. 2. In these flashovers, the insulators have damaged from lightning 18 events which is about 14.1% from 78 events. Due to high mountain terrains, the tower footing resistance is varied. The tower footing resistance is over 10 ohms about 30% of tower as shown in Fig. 3 [1].

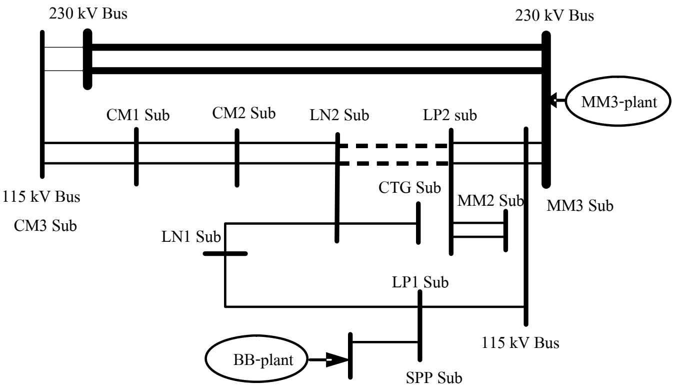


Fig. 1. The 115 kV transmission line considered in this paper.

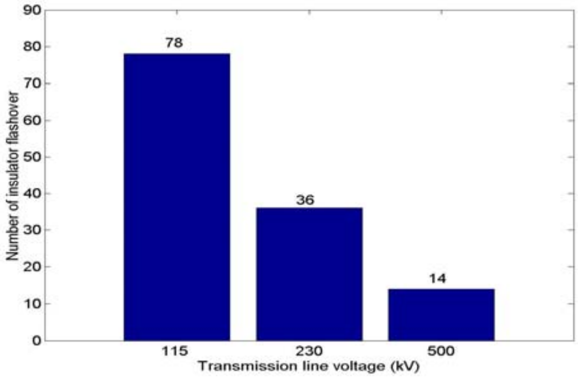


Fig. 2. Number of insulator flashover in transmission line.

This work was conducted with supported of Electricity Generation Authority of Thailand (EGAT) in collaboration with Faculty of Engineering, Chiang Mai University. The authors would like to express appreciate of these supports.

P. Yadee is with Northern Region Operation Division, Electricity Generation Authority of Thailand (EGAT), Phitsanulok, 65000 Thailand (e-mail: phairat.y@egat.co.th).

S. Premrudeepreechacharn is with Department of Electrical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, 50200, Thailand. (e-mail: suttic@eng.cmu.ac.th).

Presented at the International Conference on Power Systems Transients (IPST'07) in Lyon, France on June 4-7, 2007

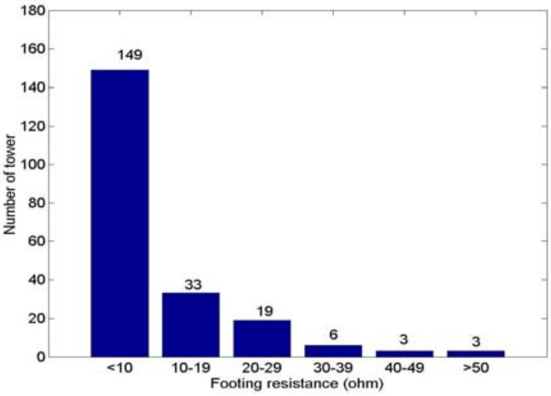


Fig. 3. Tower footing resistance along the line.

A lightning flash generally consists of several strokes which are lower charges, negative or positive, from the cloud to the ground. The first stroke is most often more severe than the subsequent strokes [2]. From the recorder, the statistic of lightning occurs in northern region during March-August 2005 shown in Fig. 4. The lightning often occurs during April to May. But the most severe lightning takes place in June. From the recorder, the positive lightning is about 5% with magnitude between 11 kA and 171 kA. But the negative lightning is about 95% with magnitude between -10 kA and -139 kA [1]. The most lightning magnitude is between -10 kA and -50 kA.

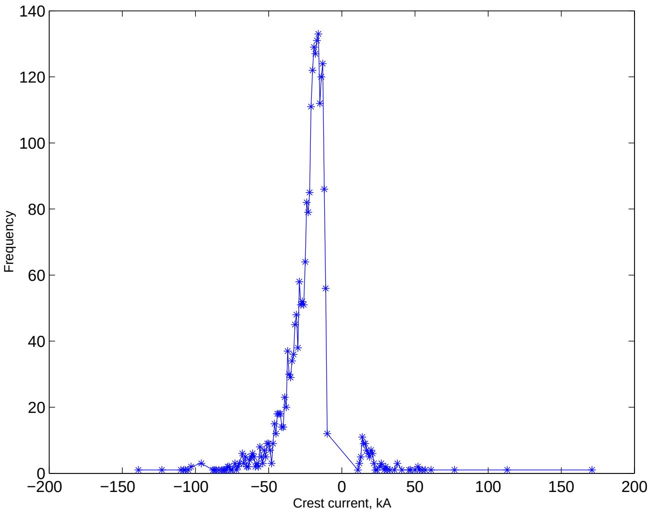


Fig. 4. Statistic of lightning in northern region during March-August 2005.

When lightning strikes a tower, a traveling voltage is generated which travels back and forth along the tower, being reflected at the tower footing and at the tower top, thus raising the voltage at the cross-arms and stressing the insulators. The insulator will flashover if this transient voltage exceeds its withstand level (backflash). Backflash voltages are generated by multiple reflections along the struck tower and also along the shield wire for shield lines at the adjacent towers. The backflash voltage across insulator for the struck tower is not a straightforward. The peak voltage will be directly proportional to the peak current.

In order to reduce the number of flashovers on the lines, there are different methods to improve the lightning performance of lines i.e. improving critical flashover of insulators, reducing grounding impedance, installing shield wire for lines without shield wire and installing lightning arresters [3]-[5]. The tower footing resistance is one of factors effected the back flashover voltage across the insulator in transmission system. In this paper, only tower footing resistance will be considered with various factors that affected back flashover.

This paper is organized as follows. Models of system studied are provided in Section II. Then, the simulation results with various factors are discussed in section III. Finally, conclusion is presented in Section IV.

II. MODELS OF SYSTEM STUDIED

A. *Lightning Source Model*

The magnitude of a current impulse due to a lightning discharge is a probability function. Low discharge levels between 5 to 22 kA may result in a higher tendency for the lightning strike to pass by any shield wires and directly hit a phase conductor. The larger lightning impulse currents may tend to strike the tower top and lead to a back flashover. This study typically used stroke front time = 1.2 μs, tail time = 50 μs as lightning source [6]-[8]. The typical lightning waveshape is shown in Fig. 5.

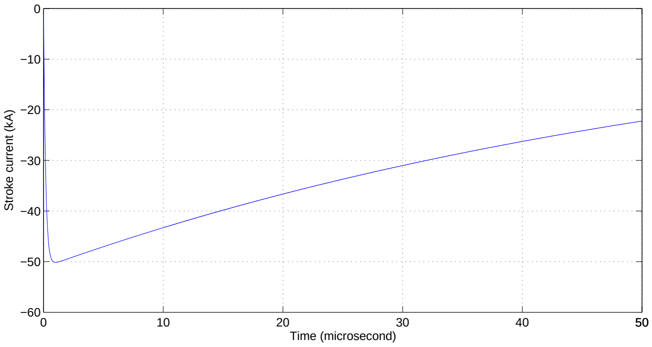
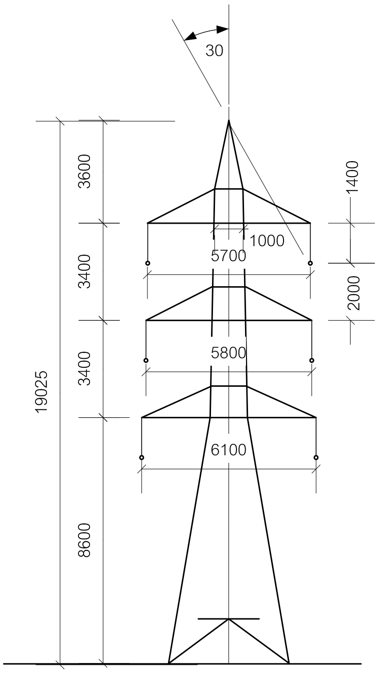


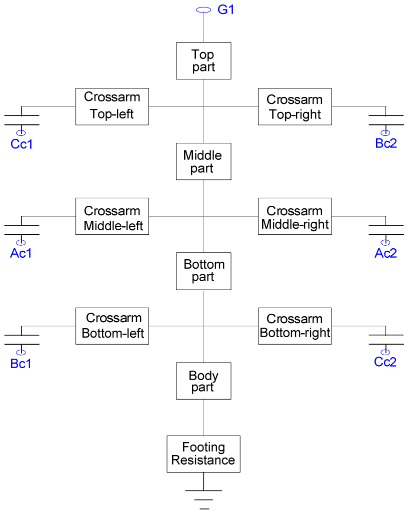
Fig. 5. Lightning source wave shape.

B. *Tower and Transmission Line Model*

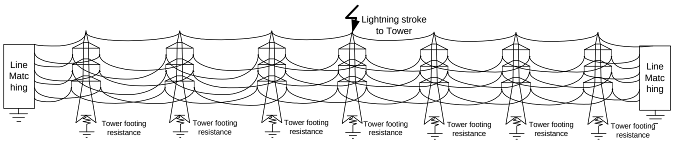
The double circuit with one overhead ground wire considered in this study is shown in Fig. 6 (a). The surge impedance of the tower and the propagation velocity down the tower are estimated and applied in a Bergeron distributed line model. Each parts of tower uses Bergeron model. The tower model is shown in Fig. 6 (b). The transmission lines are represented by distributed parameter model, with lossless high frequency approximation. Transmission line and busbars in the main surge propagation path should be modeled with frequency dependent transmission lines even if the length is only a few meters [9]. Simulation of span between tower uses frequency dependent (phase) model. The span of towers 8 spans with line matching at the end of line is simulated as shown in Fig. 6 (c). The parameter of transmission line used in this study is shown in Table I.



(a) Double circuit with one over head ground wire.



(b) Tower model using Bergeron model.



(c) The span of towers 8 spans with line matching.

Fig. 6. Modeling tower and transmission line.

TABLE I: PARAMETER OF TRANSMISSION LINE USED IN THIS STUDY.

Tower type	Member
Normal Span Length	350 m
Conductor	477 MCM. ACSR /Dia. 21.80 mm
Overhead Ground Wire	3/8 GSW(HS) /Dia. 9.144 mm
Sag of Conductor and overhead ground wire	10.62/7.66 m
Insulator type/BIL	Pin type/550kV
Insulator Number of disc/Length of one string	8,9/1500,1900 mm
Tower footing resistance	3,49,48,40,10,21,58 ohm

C. Footing Resistance Model

The tower footing resistance for fast front surges is not well understood. The impulse ground resistance is less than the measured or calculated resistance because significant ground currents cause voltage gradients sufficient to break down the soil around the ground rod. A variable grounding resistance approximation can be applied which is surge current dependent as in (1)

$$R_T = \frac{R_g}{\sqrt{1+\dfrac{I}{I_g}}} \tag{1}$$

where R_T is tower footing resistance (ohm),

R_g is tower footing resistance at low current and low frequency (ohm),

I is surge current into ground (kA),

I_g is limiting current initiating soil ionization (kA).

$$I_g = \frac{1}{2\pi}\left(\frac{E_o \rho_o}{R_g^2}\right) \tag{2}$$

where ρ_o is soil resistivity (ohm-meter),

E_o is soil ionization gradient (about 300 kV/m).

The variable grounding resistance is surge current dependent as shown in Fig. 7.

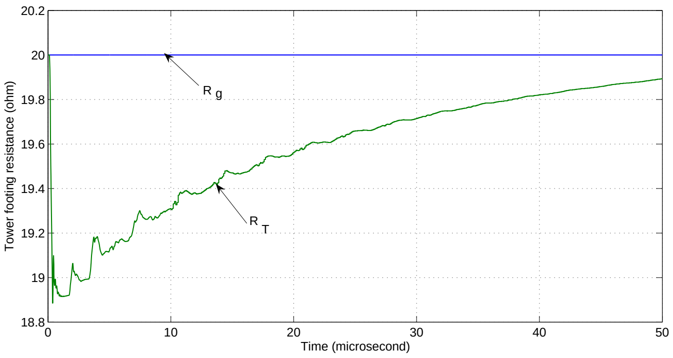


Fig. 7. Tower footing resistance.

D. Back flashover Model

Line insulators from tower to conductor can be represented as a capacitor. In this study, the tower to conductor has equivalent capacitor of 80 pF per unit. The transient-voltage withstands level of a power apparatus is not a unique number. An apparatus may withstand a high transient voltage which has a short duration even it has failed to withstand a lower transient voltage with longer duration. This characteristic of the insulator is known as the volt-time characteristic of the insulation. However, a simplified expression for the insulator voltage withstands capability can be calculated as in (3).

$$V_{fo} = K_1 + \frac{K_2}{t^{0.75}} \tag{3}$$

where V_{fo} is a flashover voltage (kV),

K_1 is 400*L,

K_2 is 710*L,

L is insulator length, (meter),

t is elapsed time after lightning stroke, μs.

The back flashover mechanism of the insulators can be represented by volt-time curves. When a back flashover might occur, a parallel switch is applied. If the voltage across the insulator exceeds the insulator voltage withstand capability, the back flashover occurs. The back flashover is simulated by closing the parallel switch. Once the back flashover occurs, the voltage across insulator goes down to zero. The waveform of voltage across insulator, when back flashover occurs at 4 µsec., is shown in Fig. 8.

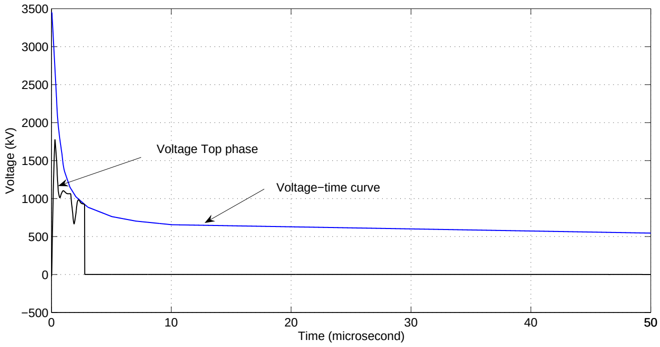


Fig. 8. The back flashover mechanism.

III. SIMULATION RESULTS

In this section, the 115 kV transmission line as shown in Fig. 1 has been modeled using PSCAD/EMTDC [9]-[10]. The tower footing resistance is one of factors effected the back flashover voltage across the insulator in transmission system as mention earlier. In this paper, only tower footing resistance will be considered with various factors that affected back flashover. The factors of this study include front time of lightning stroke, magnitude of lightning stroke, and structure of tower. The simulation results are also compared with TFlash program.

A. *Front time of lightning stroke*

Figure 9 compares overvoltage at insulator with different front time of lightning strokes between 1.2/50 µs, 2/77.5µs and 3/75 µs with magnitude 20 kA. Table II compares the flashover voltage with different front time between 2/77.5 µs and 3/75 µs and magnitude of lightning stroke between 20 kA and 40 kA. As seen from the simulation results, the shorter front time will increase the overvoltage. In addition, the higher tower footing resistance and magnitude of lightning stroke also increase the overvoltage. These will lead to back flashover at insulator.

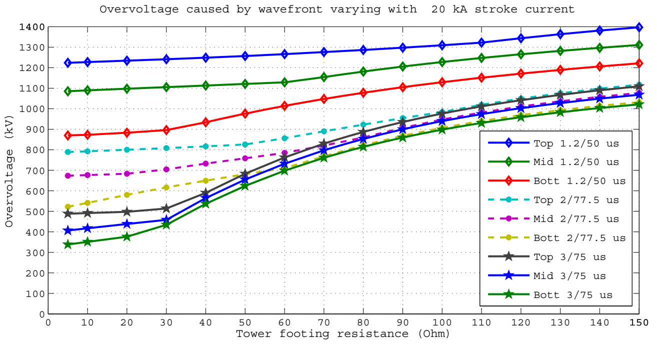


Fig. 9. Overvoltage at insulator with different front time of stroke.

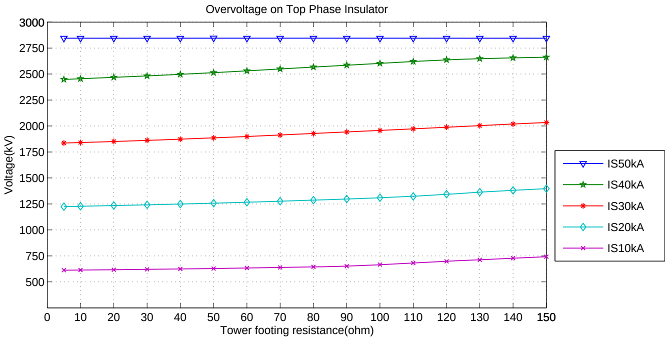
TABLE II : OVERVOLTAGE WITH VARYING FRONT TIME OF STROKE.

Tower footing resistance (ohm)	Wave front 2/77.5 us						Wave front 3/75 us					
	at stroke Is 20 kA			at stroke Is 40 kA			at stroke Is 20 kA			at stroke Is 40 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	X	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X	X	X	X	X
20	X	X	X	X	X	X	X	X	X	X	X	X
30	X	X	X	X	X	X	X	X	X	X	X	X
40	X	X	X	√	X	X	X	X	X	√	X	X
50	X	X	X	√	X	X	X	X	X	√	X	X
60	X	X	X	√	X	X	X	X	X	√	X	X
70	X	X	X	√	X	X	X	X	X	√	X	X
80	X	X	X	√	X	X	X	X	X	√	X	X
90	X	X	X	√	X	X	X	X	X	√	X	X
100	X	X	X	√	X	X	X	X	X	√	X	X
110	X	X	X	√	X	X	√	X	X	√	X	X
120	X	X	X	√	X	X	√	X	X	√	X	X
130	√	X	X	√	X	X	√	X	X	√	X	X
140	√	X	X	√	X	X	√	X	X	√	X	X
150	√	X	X	√	X	X	√	X	X	√	X	X

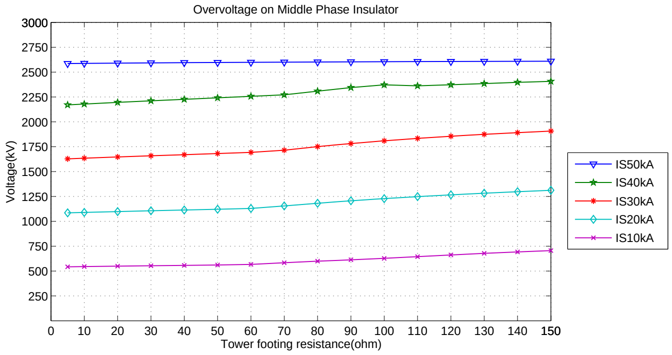
√: flashover X: no flashover

B. *Magnitude of lightning stroke*

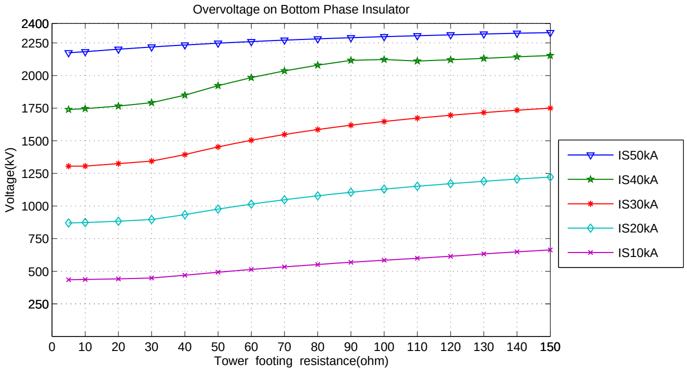
Figure 10 compares overvoltage at insulator with different magnitude of lightning strokes between 10 and 50 kA with front time 1.2/50 µs .Table III is the simulation results the flashover voltage with different magnitude of lightning strokes between 20 kA, 30 kA, 40 kA, and 50 kA. The flashover usually occurs at top phase insulator. In case of 50 kA, the flashover occurs both at top and bottom phase of insulator. However, the middle phase of insulator doesn't flashover in all cases. When the magnitude of lightning stroke is more than 50kA, the back flashover always occurs with any tower footing resistances as shown in Table III.



(a) Top phase insulator



(b) Middle phase insulator



(c) Bottom phase insulator

Fig. 10. Overvoltage at insulator with different magnitude of stroke.

TABLE III : OVERVOLTAGE FLASHOVER AT INSULATOR WITH DIFFERENT MAGNITUDE OF STROKE.

Tower footing resistance (ohms)	Overvoltage Flashover											
	at stroke Is 20 kA			at stroke Is 30 kA			at stroke Is 40 kA			at stroke Is 50 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	X	X	X	X	X	X	√	X	X
10	X	X	X	X	X	X	X	X	X	√	X	X
20	X	X	X	X	X	X	X	X	X	√	X	X
30	X	X	X	X	X	X	√	X	X	√	X	X
40	X	X	X	X	X	X	√	X	X	√	X	X
50	X	X	X	√	X	X	√	X	X	√	X	X
60	X	X	X	√	X	X	√	X	X	√	X	X
70	X	X	X	√	X	X	√	X	X	√	X	X
80	X	X	X	√	X	X	√	X	X	√	X	X
90	X	X	X	√	X	X	√	X	X	√	X	X
100	√	X	X	√	X	X	√	X	X	√	X	X
110	√	X	X	√	X	X	√	X	X	√	X	√
120	√	X	X	√	X	X	√	X	X	√	X	√
130	√	X	X	√	X	X	√	X	X	√	X	√
140	√	X	X	√	X	X	√	X	X	√	X	√
150	√	X	X	√	X	X	√	X	X	√	X	√

√: flashover X: no flashover

C. Structure of tower

Figure 11 compares overvoltage at insulator with two different structures of tower between one overhead ground wire (OHGW) and two OHGW with front time 1.2/50 µs and stroke 20 kA. Table IV compares the flashover voltage with different structure of tower between one OHGW and two OHGW. The lightning stroke is between 20 kA and 40 kA with front time 1.2/50 µs. As seen from simulation results, tower with one OHGW leads to high overvoltage across insulator.

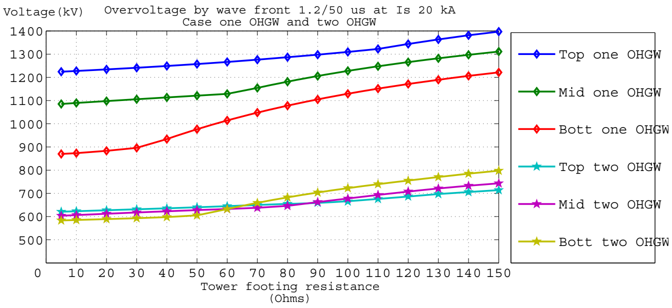


Fig. 11. Overvoltage at insulator with one OHGW and two OHGW.

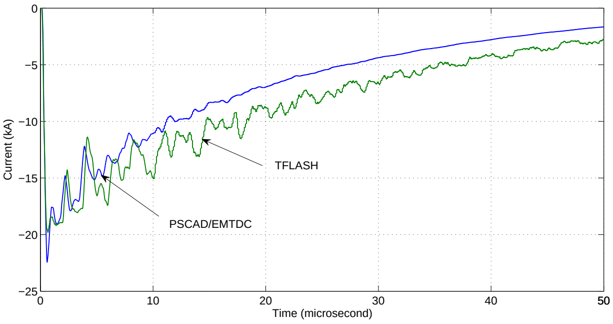
TABLE IV : OVERVOLTAGE FLASHOVER AT INSULATOR WITH ONE OHGW AND TWO OHGW.

Tower footing resistance (ohm)	Over Voltage Flashover											
	Case one OHGW at stroke Is 20 kA			Case one OHGW at stroke Is 40 kA			Case two OHGW at stroke Is 20 kA			Case two OHGW at stroke Is 40 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	X	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X	X	X	X	X
20	X	X	X	X	X	X	X	X	X	X	X	X
30	X	X	X	√	X	X	X	X	X	X	X	X
40	X	X	X	√	X	X	X	X	X	X	X	X
50	X	X	X	√	X	X	X	X	X	X	X	X
60	X	X	X	√	X	X	X	X	X	X	X	X
70	X	X	X	√	X	X	X	X	X	X	X	X
80	X	X	X	√	X	X	X	X	X	X	X	√
90	X	X	X	√	X	X	X	X	X	X	X	√
100	√	X	X	√	X	X	X	X	X	X	X	√
110	√	X	X	√	X	X	X	X	X	X	X	√
120	√	X	X	√	X	X	X	X	X	X	X	√
130	√	X	X	√	X	X	X	X	X	X	X	√
140	√	X	X	√	X	X	X	X	X	X	X	√
150	√	X	X	√	X	X	X	X	X	X	X	√

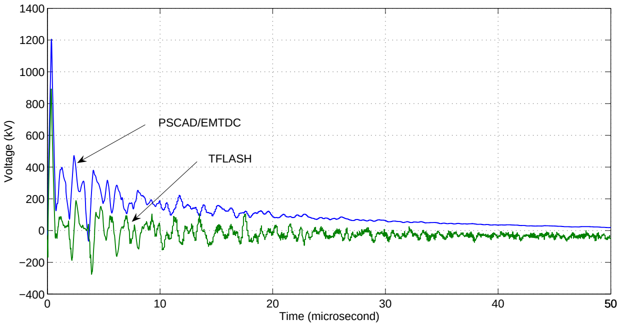
√: flashover X: no flashover

D. Comparison simulation results with TFlash

TFlash is a software package developed by Electric Power Research Institute (EPRI). It is a tool to analyze the impact of lightning activity on transmission line. To compare the voltages, current with these two programs, the models of insulators, lightning strokes, back flashover, tower, footing resistance, etc., using in PSCAD have been done corresponding to models used in TFlash. The simulation results are compared between PSCAD and TFlash as shown in Fig. 12 and Table V. The waveshape of voltage across insulator and tower footing resistance are mostly the same shape. However, the magnitude of PSCAD is less than TFlash as shown in Fig. 12. Therefore, the back flashover occurs in PSCAD more than TFlash as shown in Table V.



(a) Surge current into ground.



(b) Voltage across insulator

Fig. 12. The simulation results between PSCAD and TFlash.

Table V : Comparison simulation results between PSCAD and TFlash.

Tower footing resistance (ohm)	Over Voltage Flashover											
	Case PSCAD at stroke Is 20 kA			Case PSCAD at stroke Is 60 kA			Case TFlash at stroke Is 20 kA			Case TFlash at stroke Is 60 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	√	X	X	X	X	X	√	X	X
10	X	X	X	√	X	X	X	X	X	√	X	X
20	X	X	X	√	X	X	X	X	X	√	X	X
30	X	X	X	√	X	X	X	X	X	√	X	X
40	X	X	X	√	X	X	X	X	X	√	X	X
50	X	X	X	√	X	X	X	X	X	√	X	X
60	X	X	X	√	X	X	X	X	X	√	X	X
70	X	X	X	√	X	X	X	X	X	√	X	X
80	X	X	X	√	X	√	X	X	X	√	X	X
90	X	X	X	√	X	√	X	X	X	√	X	X
100	√	X	X	√	X	√	X	X	X	√	X	X
110	√	X	X	√	X	√	X	X	X	√	X	X
120	√	X	X	√	X	√	X	X	X	√	X	X
130	√	X	X	√	X	√	X	X	X	√	X	√
140	√	X	X	√	X	√	√	X	X	√	X	√
150	√	X	X	√	X	√	√	X	X	√	X	√

√: flashover X: no flashover

IV. CONCLUSION

This paper has described an analysis of tower footing resistance effected the backflash voltage across insulator in a transmission system. As seen from simulation results, the shorter front time of lightning stroke will increase the overvoltage across insulator. When the magnitude of lightning stroke is more than 50kA, the back flashover always occurs with any tower footing resistances. The tower with one OHGW leads to high overvoltage across insulator comparing with two OHGW. The simulation results have shown that the higher tower footing resistance has potential to insulator damage by back flashover. However, it still has other factors to consider reducing the back flashover for transmission line.

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Phairat Yadee received the B.Eng. in electrical engineering from Rajamangala Institute of Technology in 1996. He is currently pursuing the M.Eng degree at Chiang Mai University, Thailand. He is an engineer at Northern region operation division, Electricity Generation Authority of Thailand (EGAT), Thailand. His research interests include power system, high voltage, power system transient.

Suttichai Premrudeepreechacharn received the B.Eng. in electrical engineering from Chiang Mai University, Thailand and M.S. and Ph.D. in electric power engineering from Rensselaer Polytechnic Institute, Troy, NY. He is an associate professor at Department of Electrical Engineering, Chiang Mai University, Thailand. His research interests include power quality, high quality utility interface, power electronics and artificial intelligence applied power system.